Abstract

Simultaneously achieving high-sensitivity and a large resonance frequency of micromachined accelerometers is difficult because of the inherent trade-off between the two. In this thesis, we present a mechanical displacement-amplifying technique that is amenable to micromachining to enhance sensitivity without compromising on the resonance frequency and cross-axis sensitivity. Depending on the requirements of sensitivity alone or sensitivity and resonance frequency, Displacement-amplifying Compliant Mechanisms (DaCMs) are designed using the selection map-based technique, which indicates the limits of what is possible for given specifications on size and microfabrication.

In order to prove the benefits of a DaCM, we modified the designs of two very sensitive capacitive micromachined accelerometers from the literature by incorporating DaCMs and showed that, within the same footprint on the chip, the displacement sensitivity could be enhanced by more than 60% while the resonance frequency was also improved by more than 30%. As the focus of the thesis is to explore the integration of DaCMs into accelerometers, the analytical, computational, and practical aspects are discussed in detail. Both single and dual axis in-plane accelerometers are considered. The fabrication processes used are Silicon-on-Insulator Multi-user MEMS Processes (SOIMUMPs) and a customized Silicon-on-Insulator (SOI) based process. The fabricated accelerometers are packaged and brought to the product form. They were tested at the die level as well as in the packaged form.

Under dynamic conditions, the measured amplification factor of the fabricated single-axis in-plane accelerometer was observed to be 11. The overall dimension of the accelerometer was 4.25 mm × 1.25 mm. The first in-plane natural frequency of the fabricated accelerometer was found to be 6.25 kHz. The voltage sensitivity of the packaged accelerometer with the DaCM measured 26.7 mV/g at 40 Hz with differential capacitance sensitivity of 3926 ppm/g around the base capacitance of 0.75 pF.

The fabricated dual-axis accelerometer has a special configuration of twelve folded-beam suspension blocks that de-couple any displacements along the two in-plane orthogonal axes. The decoupling feature is retained even after adding the DaCMs along both the axes. The total device size was 8.6 mm × 8.6 mm. The device was also fabricated

and packaged inside a ceramic flat-pin package using hybrid die-to-die wire-bonding. Die-level dynamic characterization showed that the average geometric advantage achieved using the DaCMs is 6.2 along both the in-plane axes. The measured axial voltage sensitivity of about 580 mV/g for both the axes was achieved with a cross-axial sensitivity of less than 2% and a natural frequency of 920 Hz. The static capacitance sensitivity was found to be 0.296×10^6 ppm/g with a base capacitance of 0.977 pF. Also presented in this work is a wide-band dual-axis accelerometer without an amplifying mechanism. Its first two in-plane modal frequencies measured 14.2 kHz. The measured sensitivity of the packaged accelerometer along both the axes of the device was found to be 62 mV/g at 200 Hz.

Aiming at towards cost-effective accelerometers for small-volume markets, we also developed a single-axis and two dual-axis meso-scale spring-steel in-plane accelerometers equipped with Allegro A1395 linear Hall-effect sensors for sensing the displacement of the proof-mass. The single-axis in-plane meso-scale accelerometer also contains a DaCM. It is observed through simulation that the single-axis design with a DaCM is 39% more sensitive and has 41% more bandwidth compared to a single-axis design without a DaCM. The measured sensitivity of the fabricated single-axis spring-steel accelerometer with a DaCM was found to be 71.4 mV/g with a minimum resolvable acceleration of 14 milli-g. The unique features of the first generation of dual-axis accelerometers are that a rechargeable Li-ion battery adds to the proof-mass. It also contains a de-coupling mechanism that can decompose any planar acceleration into its axial components. The second generation of dual-axis accelerometers is more compact in size. All the mechanical elements of the accelerometers are made of EN J42/AISI 1080 spring steel foil machined using Wire-cut Electro-Discharge- Machining. The measured sensitivity of the first generation of dual-axis meso-scale accelerometers is 78 and 108 mV/g along the X and Y axes whereas the second generation device exhibits a sensitivity of 40 mV/g for both the axes. The thesis concludes that the sensitivity of a displacement-based sensor can be improved using a suitably designed DaCM without compromising the resonance frequency and hence the bandwidth. Furthermore, the work describing the development of meso-scale accelerometers also establishes spring steel as a viable material for meso-scale applications.